NEXT MEETING MARCH 20th, PAPER IN THIS ISSUE P. 157.

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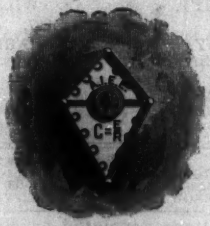

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A paper to be presented at the Ninty-fifth Meeting of the American Institute of Electrical Engineers, New York and Chicago, March 20th 1895.

[ADVANCE COPY.—SUBJECT TO REVISION.]

A METHOD FOR PREVENTING ARMATURE REACTION.

BY HARRIS J. RYAN AND MILTON E. THOMPSON.

In the designing of continuous current dynamo machinery, probably nothing has presented so much difficulty as the problem of avoiding the various evils resulting from the magnetic effects of the current that passes through the armature of the machine. Such magnetic effects are usually spoken of as armature reaction. These evils are at the present time well known, and pretty well understood by the electrical fraternity in general, and the modern dynamo designer who is not thoroughly well posted on the subject, would be wholly unable to design machinery capable of successful competition with some of the machines now on the market. The tendency of the currents that circulate in the armature coils is to produce a cross magnetism through the core at right angles to the natural field, resulting in a distortion of the natural field of the dynamo,—a piling up of the magnetic lines under the trailing pole corners, and a weakening of the field under the leading pole corners. This distortion of course, increases with the current furnished by the machine, and if not specially provided against, it may result in bringing the trailing pole corners to complete saturation, and in completely reversing the field under the leading pole corners. While this distortion is no great evil in itself, the resultant effects may be, and usually are very serious evils. All distortion of the natural field of a dynamo is sure to be attended by a diminution of the field strength resulting in a falling off of the E. M. F. produced by the dynamo, and if the distortion be very great, no amount of compounding will cause such a dynamo to give constant potential. The most serious evil,

however, arises from the fact that the weakening of the field at the leading pole corners results in a shifting forward of the neutral point or diameter of commutation of the dynamo. The amount of such shifting depends on the amount of distortion, and this in turn varies with the load on the machine. Consequently if the brushes are set on the normal neutral point when running light, the machine will spark badly under load and it becomes necessary to keep shifting the position of the brushes to meet every variation in load. More than this, unless the pole tips or armature lugs are saturated, a point of loading is soon reached, beyond which one finds no diameter of sparkless commutation, and the output of the machine has reached a maximum at this point, notwithstanding the fact that the load may be below that allowed by a safe heating limit. These facts as before stated, are well understood by the more competent dynamo designers, and receive the

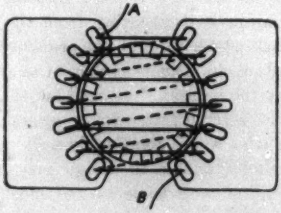

FIG. 1.

most careful consideration in the preparation of new designs. It must be confessed, however, that the principal part of the knowledge on this subject is the result of dearly bought experience and costly experiments, rather than of scientific study of the principles involved. Designers of dynamo machinery, with few exceptions, instead of aiming to prevent armature reaction, have endeavored to avoid its bad effects in various ways, and in some cases with fairly good results. The distorting effects of armature reaction become less, in proportion as the reluctance of the air-gap and armature core teeth are increased, and the wiser designers of the present day, taking advantage of these facts, are producing some very creditable machines. Probably some of them still believe, as some of the very best authorities on the subject of dynamo machinery have confessed to believing until quite re-

cently, that armature reaction is a necessary evil, and if it were possible to prevent it entirely, the whole utility of the machine would disappear at the same time.

While making a thorough consideration of the subject of armature reaction some time since, one of the authors of this paper, devised a means of entirely preventing armature reaction and resulting field distortion. On looking up the literature of the subject we found, mainly through the patent office records, that there were several workers in the field at a comparatively early date, viz.: Prof. Elihu Thomson, Messrs. Andrews and Spencer, Mather, Forbes, and possibly one or two others. The specifications given by Andrews and Spencer indicate clearly the technical side of this method for preventing armature reactions, while

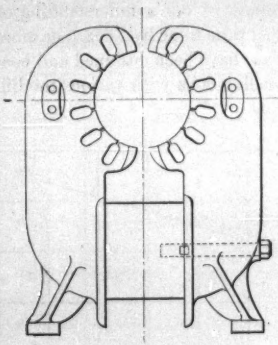

FIG. 2.

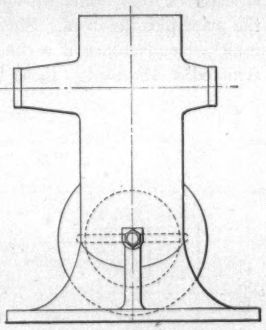

FIG. 3.

our part appears in the development of a plan for the practical application of the scheme technically outlined by them in 1886. This method consists in general in surrounding the armature with a stationary winding exactly similar in its magnetic effects to the armature winding, but directly opposed to it, and thus completely balancing all armature reaction. Fig. 1 is a diagram that shows the manner in which the coils are applied. Holes are provided immediately back of the pole surfaces, and through these holes are wound conductors which are placed in series with the armature. *The number of ampere-turns of the balancing coils crossing each pole face is equal to, and opposite in direction to the number of ampere-turns on the corresponding part of the armature.*

A small bi-polar machine of about $2\frac{1}{2}$ kilowatts capacity was designed, constructed and tested during the spring and summer of 1891, and the results obtained were very encouraging, demon-

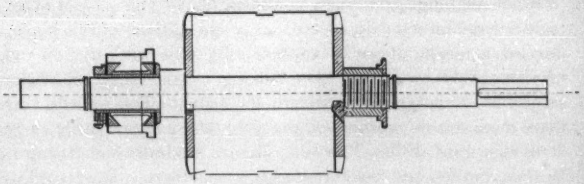

FIG. 4.

strating beyond doubt the correctness of one's understanding of the principles involved. Since that time some half-dozen or more multipolar machines of various sizes have been designed and constructed. All employ these balancing coils with various modifi-

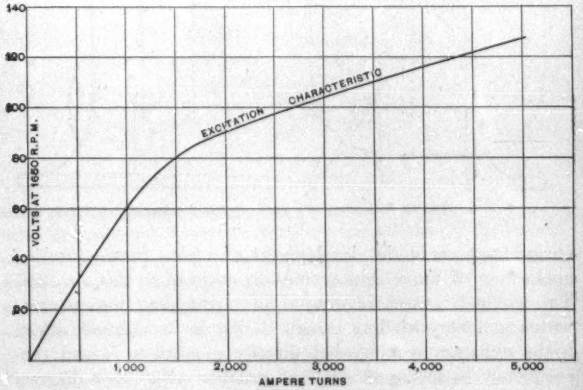

FIG. 5.

cations of design and gave the following results.

Brief mention of these results have been made heretofore in the literature, while a complete report of the same is now made for

the first time.[1] Figs. 2 and 3 are side and vertical views of the first machine; Fig. 4 is a side view of the toothed armature; and the following are the essential data of construction:

Field of cast-iron, two poles	
Diameter of the armature core over all	6 in.
Length of armature core	6 in.
Number of teeth	64
Number of commutator bars	64
Armature turns per bar	3
Size of armature conductor, B. & S. G.	12
Resistance of armature, ohms	.34
Speed, R. P. M.	1800
Output, amperes	25
Output, volts	100
Turns on field, 250 of No. 7, B. & S. G.	
Balancing turns, wound in six grooves per pole face, 16 turns per groove, or a total of 96 turns of No. 8 B. & S. G.	
Resistance of balancing coils, ohms	.24

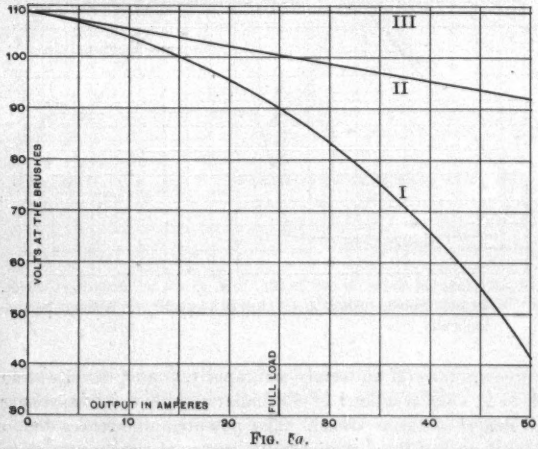

FIG. 5*a*.

For dimensions of slots to accomodate balancing winding see Fig. 2.

The diagram of Fig. 5 gives the excitation characteristic at no load and a speed of 1660 R. P. M. Fig. 5*a* is a diagram of results

1. "On a Method for Balancing Armature Reaction," *Sibley Journal of Engineering*, Oct. 1892, Vol. VII, p. 17. "Electromagnetism and the Construction of Dynamos," by Dugald C. Jackson, p. 172.

obtained by actual observation made on this machine when overloaded at normal excitation and speed, with and without the balancing coils. The pressure readings were taken at the brushes, and do not include the drop through the balancing coils when they were used. Characteristic I was obtained without the use of the balancing coils; characteristic II with the balancing coils; and characteristic III is the same as II with the balancing coils, when corrected for drop in pressure due to armature resistance. The same field excitation of 2600 ampere-turns was maintained at all times. It should be noted that without the balancing coils

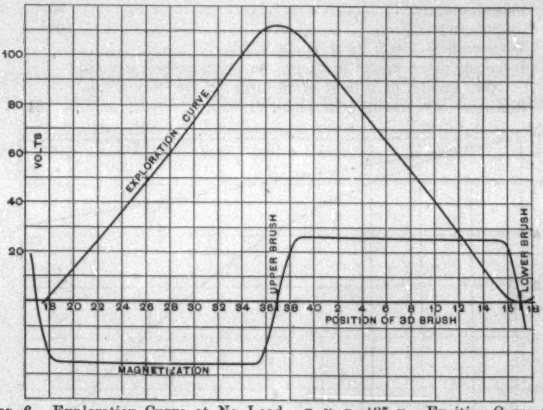

FIG. 6.—Exploration Curve at No Load. E. M. F. 105 V. Exciting Current, 10.4 C. Speed, 1,800 R P. M. Operated as a Motor. Without Balancing Coil.

the pressure falls off uniformly and rapidly, from 109 volts at no load, to 41 volts at a load of 50 amperes, with violent sparking at all ranges of the overload. The potential differences due to the resistances of the carbon brushes were not nearly enough to reverse the currents in the coils while under the brushes, against the opposing E. M F.'s produced by the reversed fields established by the powerful armature reactions. The E. M. F. at the brushes falls off with a rapidity that is greater than that which would be due alone to the resistance of the armature, because of the throttling action of those parts of the magnetic circuit that become

saturated by the concentration of the induction by the route of the trailing pole corners. In marked contrast was the corresponding behavior of the machine with the balancing coils in circuit, as illustrated by curve II. There was no sparking at any point of the overloading; the brushes were fixed on the no load position, *i. e.*, at the zero of field induction, and at all loads the currents in the sections were easily reversed without spark, by the potential differenees that were caused by the resistance of the carbon. There was no observable falling off of the induction

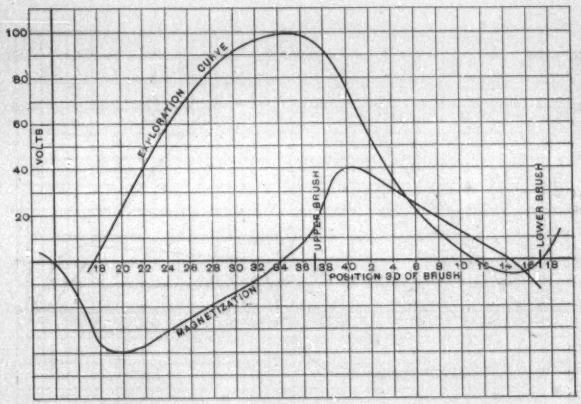

FIG. 7.—Exploration Curve, Full Load. $v. = 97.$ $c = .24.$ Exciting Current, 10.4 A. Speed, 1,800 R. P. M. Operated as a Dynamo, Without Balancing Coil.

through the armature under load when the balancing coils were used; and this is clearly indicated by curve III, which as stated before, is curve II corrected for the fall of pressure due to the resistance of the armature.

The diagrams with their respective legends that are given in Figs. 6 to 14 inclusive, are self-explanatory. Separate excitation was used on all the experiments on this machine. The pilot or third brush method was used for making the field explorations. In each instance the "exploration curve" is a record of the pilot brush readings, while the ordinates of the "magnetization" curve

are proportional to the actual induction densities as deduced from the exploration curve. Fig. 6 shows that the induction is uniform over the entire pole face at no load, normal excitation and speed, as it should be without the coils. The motion of the armature conductors is from right to left. Fig. 7 shows the production of a reversed field in the presence of the brushes at a full load current, and normal field excitation without the balancing coil. Fig. 8 gives the result obtained for the same conditions, except that the balancing coil was used. The magnetization curve shows that the balancing coil slightly over-compensated the

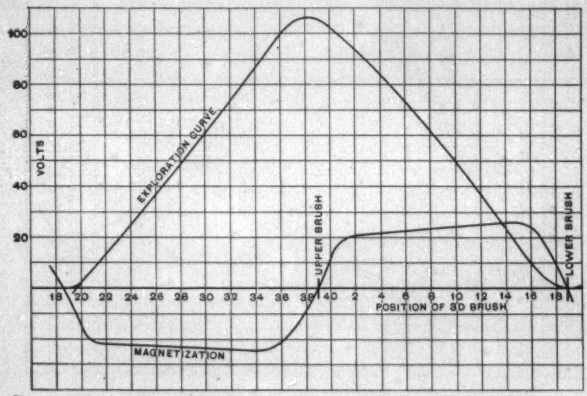

FIG. 8.—Exploration Curve, Full Load. v. = 105. c. = 24.5. Speed, 1,800 R. P. M. Exciting Current, 10.4. Operated as a Dynamo, With Balancing Coil.

magnetic action of the armature, since the induction of the trailing pole tip is weakened, and that of the advanced tip strengthened, a phenomenon just the reverse of what commonly occurs. The diagrams of Figs. 9 and 10 are for substantially the same conditions as those of 7 and 8, except that the machine was operated as a motor. The results are precisely those one would expect—the same as those obtained for the dynamo, except that the sides on which the higher inductions occur are reversed in position. Figs. 11, 12, 13 and 14 give interesting results that were obtained by lowering the field E. M. F. and then operating as before. By ope-

rating as a dynamo or motor without the coil, extraordinary powerful armature reactive effects are produced. It is seen that the brushes are in the presence of a reversed field that is quite as great as the normal no-load field of 3000 lines per square centimetre, and moderate sparking with the carbon brushes occurred. Here the balancing coils bring out an interesting effect. One would expect that the effects of their over-balancing action would be felt more at lower excitations. In this experiment the induction at the advance pole tip or the position of the "commutation

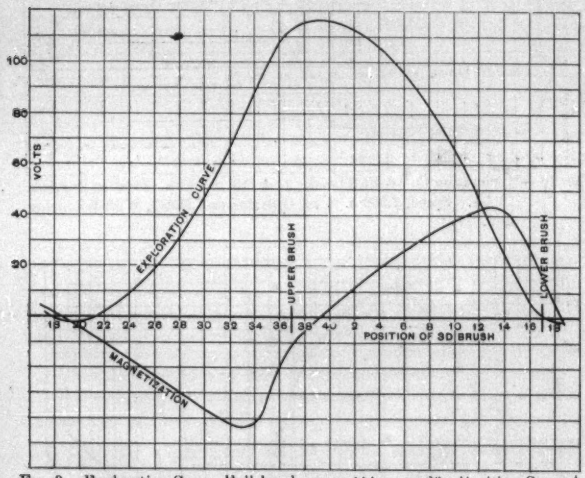

FIG. 9.—Exploration Curve, Full Load. V. = 114. C. = 26. Exciting Current, 10.4 A. Speed, 1,920 R. P. M. Operated as a Motor, Without Balancing Coil.

fringe" is almost doubled from the normal no-load value instead of being diminished as is ordinarily the case. It is appreciated that the effect of such a behavior is to increase the strength of the commutating fringe at the leading pole tip in proportion to the load, thereby diminishing the range of change of the non-sparking point with metallic brushes, or enabling carbon brushes to be easily adjusted so that when in a fixed position there will be practically no sparking at all ranges of load.

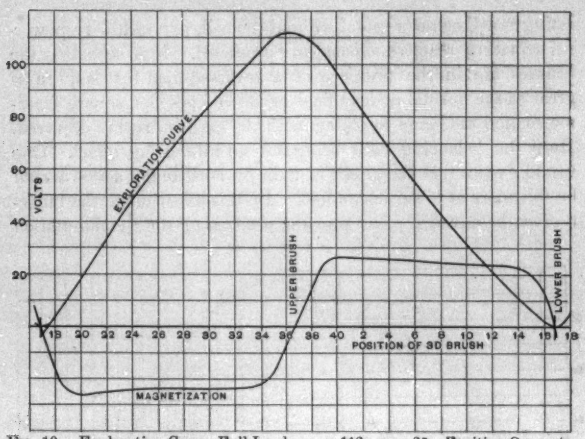

FIG. 10.—Exploration Curve, Full Load. v. = 112. c. = 25. Exciting Current, 10.4 A. Speed, 1,920 R. P. M. Operated as a Motor, With Balancing Coil.

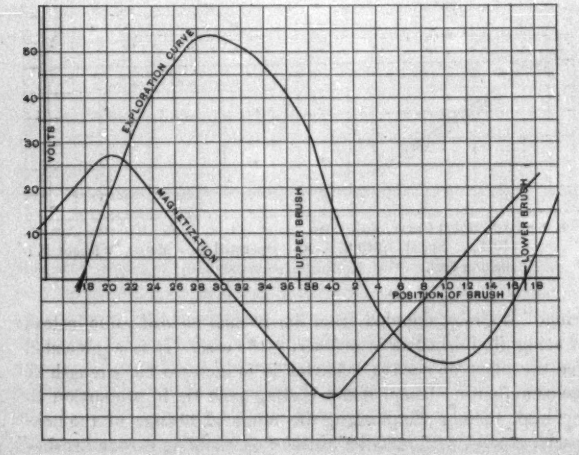

FIG. 11.—Exploration Curve, Full Load. v. = 36. c. = 20. Exciting Current, 2.5 A. Speed, 1,800 R. P. M. Operated as a Dynamo, Without Balancing Coil.

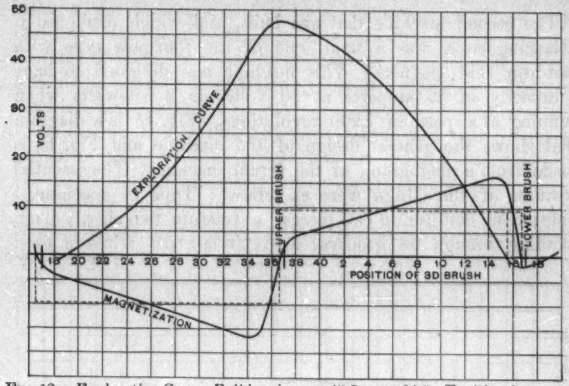

FIG. 12.—Exploration Curve, Full Load. v. = 48.5. c. = 22.5. Exciting Current, 2.5 A. Speed, 1,800 R. P. M. Operated as a Dynamo, With Balancing Coil.

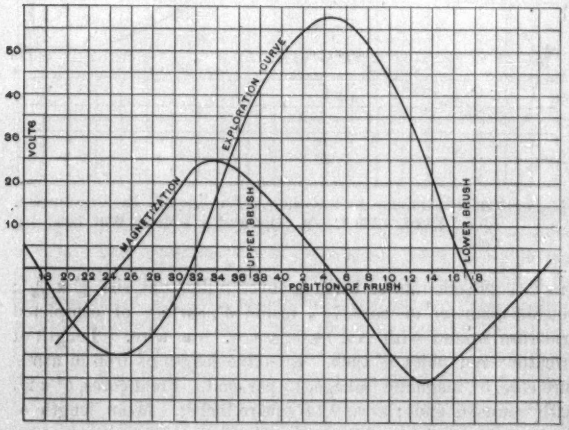

FIG. 13.—Exploration Curve, Full Load. v. = 36.5. c. = 23.5. Exciting Current, 1.6 A. Speed, 1,600 R. P. M. Operated as a Motor, Without Balancing Coil.

The second machine that was built, and which made use of balancing coils, was a small one of the four-pole type with cast-iron field magnets. This machine was designed to have a capacity of 25 amperes at 80 volts, or 2 kilowatts when running at a speed of 1,200 revolutions. Fig. 15 is a diagram that shows the general design of the machine, and Fig. 16 is made from a photograph of the actual machine. The essential features of the design were as follows: Type of machine, 4 pole; field, cast-iron in two pieces. Armature two circuit drum winding through 58 grooves; 5 No. 10 B. & S. G. wires in each

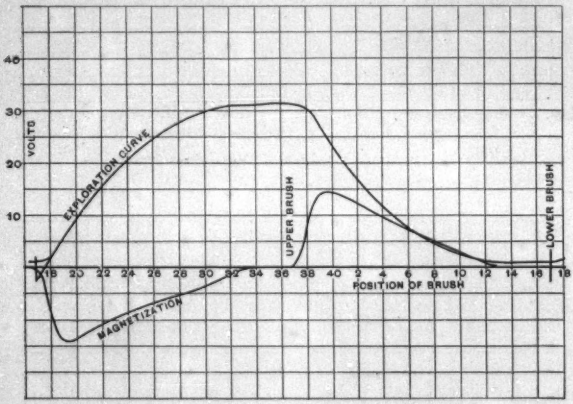

FIG. 14.—Exploration Curve, Full Load. V. = 31. C. = 24. Exciting Current, 1.6 A. Speed, 1,520 R. P. M. Operated as a Motor, With Balancing Coil.

groove; 29 commutator bars; grooves milled out, size $\frac{5}{8}''$ x $\frac{3}{64}''$; outside diameter of core $7\frac{1}{2}''$, inside $3''$, surface of completed armature wound with No. 14 B. & S. G. iron wire. Length of armature and poles, $6''$ each. Effective length of iron in armature core, $5''$, magnetic leakage, 15 per cent. Field cores, $5''$ x $2''$, with rounded ends; area, 9.14 square inches. Mean length of field magnetic circuit, 12.5 inch. Magnetic density in armature core, 5,400 gausses; in air-gap, 4,900; in the armature teeth, 8,400; in the field cores, 6,800. Field winding, mean length of turn, 15 inches, requisite exciting M. M. F. for field circuit, 1145

gilberts; for armature, 31.3 gilberts; for air-gap, 1258 gilberts; or a total of 2,434 gilberts; size of field wire, No. 18 B. & S. G. Number of holes for balancing coils, five in each pole-piece, even conductors per pole or 140 conductors total. Weight of complete machine, 400 pounds.

An examination of this data discloses the fact that no regard is had for the pernicious effects that are ordinarily met with in the use of so short an air-gap with a comparatively large number of armature ampere-turns. With the use of the balancing coils no such effects were observed; the machine performed precisely in accordance with the original estimate made in designing it, and exactly as theory shows that ordinary machines would perform if armature reaction were entirely absent.

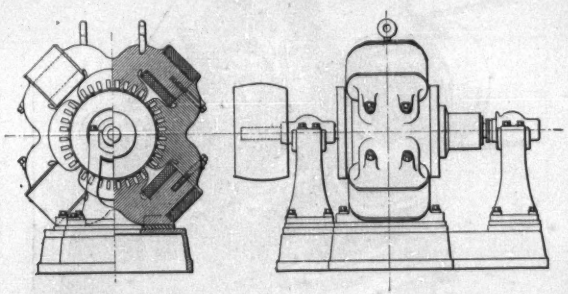

FIG. 15.

During test the machine was belted directly to a ten H. P. Sprague motor, and ran at a speed varying from 1,500 to 1,650 R. P. M. The commutator was quite small for a four-pole machine; it had only 29 segments and was very poorly suited for the pressure of 100 volts at which it was tested. The machine was loaded down to 43 amperes at 100 volts, speed 1,650, and an exploration curve taken around the commutator. This curve is shown in Fig. 17 and clearly indicates the entire absence of field distortion. It was found that the machine would easily carry a load of 45 amperes continuously without overheating. After this curve was taken, the machine was loaded down as heavily as the driving belt would permit, and ran at a load of 80 amperes and 80 volts for about fifteen minutes. Under this load there

was no appreciable difference from light load in the behavior of the commutator. The balancing coils were short-circuited for an instant while the machine was loaded to 40 amperes, and the vicious sparking that ensued, showed that the dynamo could not be operated at this load without the balancing coils Indeed the indications were, that it would have been fatal to the welfare of the commutator, and perhaps to the armature itself to entirely cut out the balancing coils when the machine was carrying this load. The balancing coils were then cut out and the dynamo gradually loaded down to test the performance without balancing

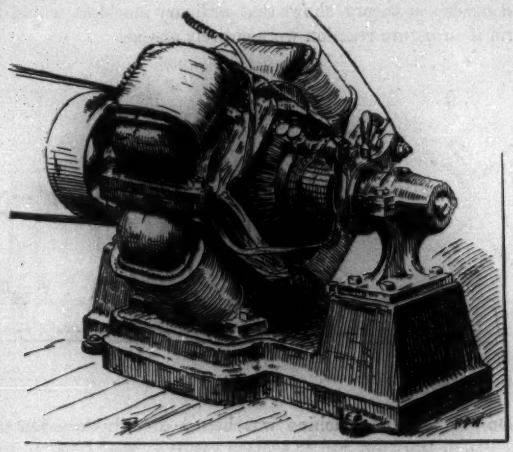

FIG. 16.

coils. The brushes were shifted forward to prevent sparking as the neutral point changed, and the potential was kept up as much as possible by cutting out field rheostat. The maximum current reached was 37 amperes at 85 volts, with field rheostat all out, and speed 1,800 R. P. M. At this speed, and with this excitation, the machine would have given 120 volts, instead of 85, if the balancing coils had been used to prevent armature reaction. After a load of 37 amperes was reached, it was found impossible to raise the current by cutting down the external resistance, owing to the rapid fall of potential due to armature reaction.

The capacity of this particular machine was about doubled by the addition of the balancing coils, and a comparison of the 37 amperes maximum with the 80 amperes which was by no means the highest possible current, shows that the overload capacity of this machine may be doubled by their use.

Two more machines of the same general design as the latter were built and tested. These machines were built with field magnets of mitis metal, and the pole-pieces and armature cores were one inch longer than the machine last described. The armature windings were different from each other and different from the cast-iron machine. One was wound with a two circuit winding, and the other with a four circuit winding. Total weight of each machine was 450 pounds. Each machine, after

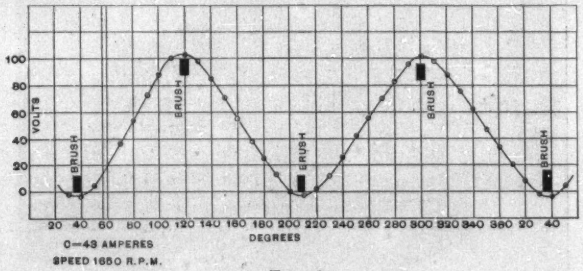

FIG. 17.

running at 1200 R. P. M., carried a load of 85 amperes at 110 volts for two hours continuously, and was then loaded down to 100 amperes for a quarter of an hour. The performance of the machines confirmed in every particular the results previously obtained.

Two other machines of this same type were built,—one of which was wound for a current of ten amperes at 600 volts, and the other for a current of 550 amperes at 110 volts, or 60 kilowatts.

This type of machine was found to be expensive to construct, and owing to its exceeding compactness, very hard to ventilate. The main plan in view when designing these machines was to lessen

the total weight for a given output by taking advantage of the fact that when the balancing coils are used, one may greatly increase the amount of copper on a given armature, and still obtain the same satisfactory performance at the commutator. As Fig. 15 indicates, a too compact design was adopted; the ventilation was cut down so that full benefit of the large amount of armature copper was not obtained.

Machine No. 7 was therefore built with a field of the ring type. This machine embodied a number of important improvements in details of construction as will be hereafter noted. Fig. 18 shows a photograph of the machine from the pulley end, and Fig. 19 is a view from the commutator end. Fig. 20 is a view of the arm-

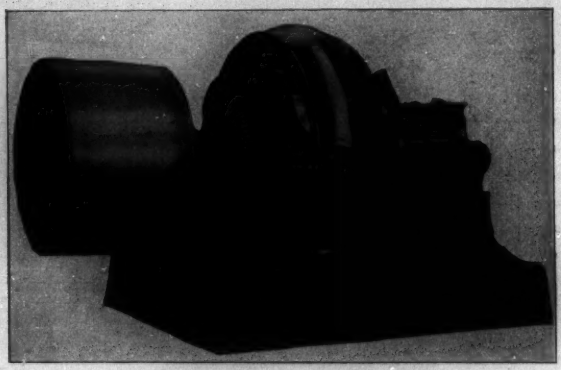

FIG. 18.

ature which was wound with No. 6 wire cable. Both commutator and armature core were hollow, and the winding thoroughly ventilated. All armature coils were wound simultaneously, and the winding was perfectly symmetrical. Fig. 21 is a view of the pole ring. This ring which carries the six balancing coils was made in halves, and the pole-pieces were joined together by small connecting lugs as seen in the figure, in order to make the casting continuous. This construction permits the field coils to be wound in a lathe, and to be easily removed from the fields at will. It is also a decided advantage to have the balancing coils and the pole-pieces through which they are wound, separable from

the rest of the field. The following are the more important details of the design of this machine:—Capacity, 91 amperes at 110 volts or 10 kilowatts. Type of machine, six-pole, ring field of steel. Armature winding of cable through grooves in core. Armature ten inches in diameter outside, by five inches inside; number of grooves, 61,—six conductors per groove. Grooves, $\frac{7}{32}''$ wide by $1\frac{1}{4}''$ deep; number of commutator bars, 122; total number of conductors, 366. Armature core and pole-pieces, five inches

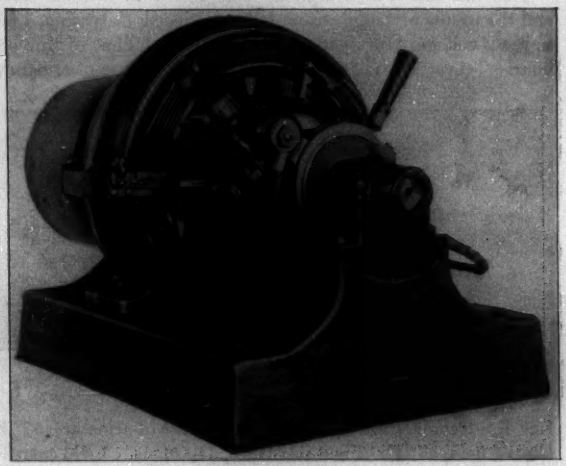

FIG. 19.

long. Mean distance between poles, $\frac{3}{4}''$. Total magnetic flux, 1,800,000 webers; maximum density in armature teeth, 14,400 gausses. Maximum radial density in armature core, 8,500. Mean air-gap density, 5.000. Maximum field density, 14,000; length of air-gap, $\frac{1}{16}''$; M. M. F. for field, 642 gilberts; for air-gap, 1,600 gilberts; for armature, 99 gilberts; total M. M. F., 2,341 gilberts. Fields wound with No. 20 B. & S. G. wire. Armature, 366 conductors of No. 6 cable; five holes in each pole-piece for balancing

coils. Balancing coils wound with copper ribbon. Compounding, two series turns on each field coil.

Weight of field casting, actual	213 lbs.
" " armature core, shaft and spider	98 "
" " " and commutator complete	185 "
" " " copper	48 "
" " copper for balancing coils, actual	55 "
" " field copper, actual	40 "
" " dynamo complete including base bearings, brush holders, brushes and 14 × 9 inch pulley	865 "

This machine was completed and tested in October 1894, and the results of test were as follows: Speed of dynamo, 1,065 R. P. M.; voltage, 110. Current, 110 amperes. Time of run, one hour. Temperature of room, 71° F. Temperature of armature,

FIG. 20.

128° F. Temperature of field, 108° F. Rise of armature, 57° F. Rise of field, 37° F. Field resistance, 110 ohms. Field current, 1.00 amperes. Field energy, 110 watts. Armature resistance, .0512 ohms. Armature winding loss, 618 watts. Balancing coil resistance, .0202 ohms. Balancing coil loss, 242 watts. Series resistance, .00955 ohms. Series loss, 115 watts. Core loss, friction, etc., obtained from energy absorbed as motor running light at full pressure, 450 watts. Total losses, 1,408 watts. Total output, 12,100 watts. Gross energy absorbed, 13,508 watts. Commercial efficiency, 88.7 per cent. For lighter loads the efficiencies are given by the curve in Fig. 21*a*. This test was made after the machine had been running for several hours under various loads. On another occasion the machine ran one hour and twenty minutes under a load of 115 amperes at 105 volts with a rise of

temperature of armature of 48° F. While carrying this load, which it will be noted is 25 per cent. above the rated full load, the pilot brush exploration curve, shown in Fig. 22, was taken. This curve shows the entire absence of armature reaction. The machine has also carried 135 amperes for one-quarter hour, and has several times been loaded down to 180 amperes for a few minutes at a time without damage.

While the "balancing coils," as may have been seen from the foregoing results, entirely prevent field distortion and shifting of

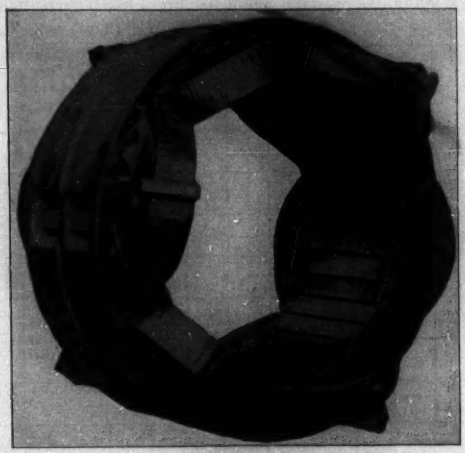

FIG. 21.

the neutral point, there is still something lacking for ideal commutation. In a constant potential dynamo, the following are the conditions for perfect and sparkless commutation. When a coil is short-circuited as it passes under a brush, the current in the coil must fall to zero, reverse, and rise exactly to the original value in the opposite direction at the instant the short-circuited coil is opened by the passage of the tip of the brush from the commutator bar. To bring about this reversal properly, the short-circuited coil must move during short-circuit through a field whose strength is proportional to the armature current. In other

words, the short-circuited coil should move in a neutral field when the machine is unloaded, and should move in a field of considerable strength when fully loaded. The field strength required for sparkless commutation under any particular load depends first on the resistance of the short-circuited coil; second, the self-induction of the short-circuited coil; and third, the duration of the short-circuit which in turn depends on the width of brush and speed of the dynamo. Preferably the short-circuited coil should move in a uniformly distributed field. It is evident from this consideration that we do not get the conditions for perfectly sparkless commutation even where armature reaction is prevented

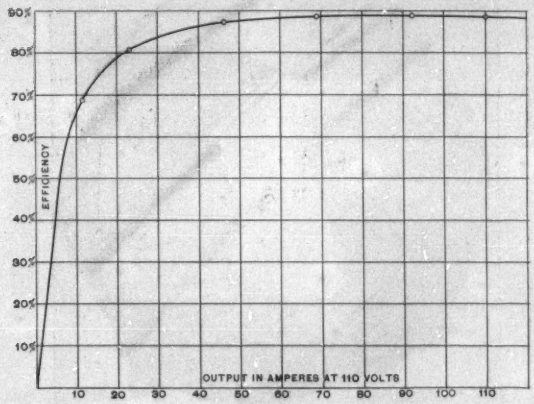

FIG. 21a.

if we attempt to commutate under pole corner. It is also evident that if armature reaction and field distortion *are* not prevented, we get just the opposite effect on our commutation from what we would wish—that is, our commutation field grows weaker as the current increases, instead of growing stronger as it should. From this we may set it down as a settled fact, that no dynamo of any considerable voltage and range of capacity which commutates under the leading pole corner and is not provided with some special spark preventing device or arrangement for preventing field distortion can be worked from no load to full load without sparking or without shifting the brushes. During

their experimental work on balancing armature reaction, the writers devoted considerable time to the problem of sparkless commutation, and as a result have devised an improvement to be used in connection with balancing coils, by means of which ideal commutation is attained. The device is simple, and accomplishes the desired end perfectly. It consists in bridging across the gap between the pole-pieces, attaching a commutation lug to the center of this bridge and making this lug the center of the balancing coil, the latter being provided with a few extra turns, The arrangement is shown in Fig. 23, which represents a portion of the field circuit sectioned centrally in the plane of rotation. Referring to the figure, *aa* and *bb* are two field coils wound round the pole necks C and D; G is the commutation lug which is at-

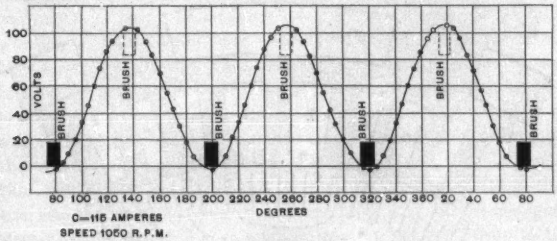

FIG. 22.

tached to the middle of the lugs H I, which latter, bridge across the gap between the pole-pieces E and F. The balancing coil (not shown) is wound through the holes K, L, M, N, O, P, with the commutation lug G at the center of the coil. The path for magnetism is indicated by the dotted lines. It will be noticed that a part of the magnetic lines are shunted across between the pole-pieces E and F, through the bridge lugs H I, and do not pass through the armature. Now when there is no current in the armature or balancing coils, it may be easily seen that the fall of magnetic potential from E to F is the same by either the path through the bridge lugs, or through the armature, and that the commutation lug G attached to the middle of the bridge lugs, must be at the same

magnetic potential as the armature teeth opposite, for the latter are connected to the middle of the armature circuit. Therefore, under these conditions, which are practically what we have when the machine is running light, there will be no field between the surfaces R and S of the commutation lug and armature respectively. If then our brushes are set so that commutation takes place while the short-circuited coil is passing under the commutation lug, we have the correct conditions for sparkless commutation. When the machine is loaded, the excess of ampere-turns of the balancing coils over ampere-turns of the armature, brings a magnetizing force to bear on the lug G in the direction indicated by the arrow.

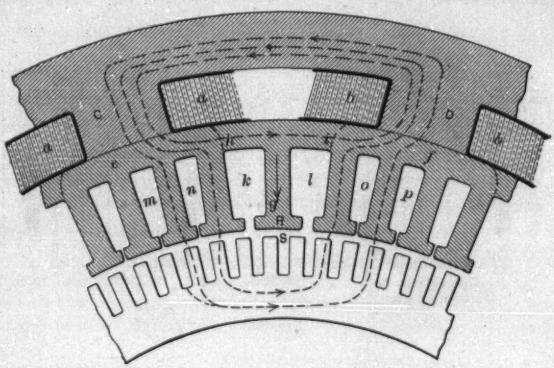

FIG. 23.

This tends to increase the magnetism through H and diminish it through I, but as H is normally saturated, there will be very little increase in its magnetism. There will, however, be a field established under the commutation lug, by the deflection of the lines from the bridge lug I through the commutation lug and armature, and it is evident that the stronger the current in the balancing coils, the stronger will be the field under the commutation lug. We, therefore, again have the correct condition for sparkless commutation when the machine is loaded, provided our balancing coils are so proportioned as to give us a commutation field of proper strength. From this it will be seen that at all times the

commutation field is proportional to the current, and that for all loads we have the requisite conditions for sparkless commutation without shifting the brushes.

So much for the theory of this plan, and now comes the important question "Will it work in practice?" We are able to answer without hesitation that such a machine performs as well in practice as in theory, and that actual tests show absolutely sparkless commutation from no load to 50 per cent. overload with fixed metallic brushes. More than this, practice confirms another theoretical advantage of this improvement which we have not yet touched upon. It will be noticed that the commutation field is obtained by the deflection of lines from bridge lug 1 and that the lines so deflected, pass through the armature, and consequently are added to the useful magnetic field. We might expect from this, and from the fact that since the brushes are midway between the poles, there are no back ampere-turns, that the machines would compound somewhat without a regular compound winding. This theory was entirely sustained by actual trial. It was found under test, that by slightly shifting the position of the brushes forward or backward, it was possible to make a few of the armature turns act with, or against the field winding at will, and this without any effect on the sparkless commutation, so long as the brushes were not moved beyond the limits of the commutation field. The result of this is that by simply shifting the brushes, the compounding of the machine may be so changed that it can be adjusted at any point from 10 per cent. drop to 10 per cent. over-compound, and this without interfering with the commutation in any way.

Thus by this simple contrivance we attain sparkless commutation without shifting of brushes, and a compounding adjustable at will. It is not claimed that the broad idea of a commutation lug is new, but the success of such a contrivance depends altogether on the way in which it is applied. Unless the magnetic effects of the armature currents are taken care of properly, a commutation lug would prove worse than useless and we would be likely to get an effect just the opposite of that desired. Thus it will be seen that the advantages which we have shown as resulting from the use of this system of commutation, arise not from the use of a commutation lug alone, but from its use in connection with coils for balancing armature reactions. Direct experiment has shown that this system of commutation will not

give satisfactory results except when used in connection with balancing coils. Aside from the effect on commutation, however, balancing coils have some very important advantages to which we will briefly call attention. By their use the capacity of a machine of given size and weight may be greatly increased, and the resulting machine still be far better in quality and operate more satisfactorily than those of ordinary design. The reasons for drawing this conclusion are briefly these: Since the output of these machines is in no degree limited by armature reaction, it is possible to load the armature with as much copper as can be crowded onto it and to work this greatly increased amount of copper to its safe heating limit,—the heating of the armature conductors being the only limit to the capacity of a given armature; and the core losses may be much less in a machine of this type since the magnetic densities in the core may be made as low as we choose, and this will permit the armature to be loaded with still more copper.

With the standard peripheral velocity of 3,000 feet, it is easy to get an output of 20 to 30 watts per pound total weight of dynamo, and for large sizes of machines even still greater output per pound. With armature reaction balanced, there is no necessity for high reluctance in air-gap and teeth, and it is therefore made as low as possible for the whole magnetic circuit. The air-gap is reduced to what suffices for clearance, and the armature and field are worked at as low densities as is consistent with economy of iron. By this means from one-half to three-fourths or even more, of the ampere-turns on the field may be saved with a corresponding saving in field copper and field energy. This, and the reduced core losses reduce the fixed losses in the dynamo to a minimum, bringing them below what is possible with the ordinary construction, and the result is a very material change in the shape of the efficiency curve of the machine. Since the fixed losses are very small, the machines will have unusually high efficiency on light loads, the efficiency curves run up very sharply and bend off to a very uniform efficiency throughout the greater part of the range of load. This is a very decided advantage where machines are expected to work under considerable range of load as they usually are, both for lighting and power purposes. In designing machines it is also an easy matter to proportion materials according to their relative prices. Thus, with a design containing a given amount of copper, we can increase the copper

slightly and reduce the iron and steel, keeping the capacity of the machine the same, and thereby effect a saving in cost perhaps, or we may increase the iron and steel and reduce the copper to effect a similar saving. With ordinary designs such an adjustment as this would be out of the question, except at a sacrifice of valuable qualities of the machine, for the invariable rule is that the M. M. F. of the armature ampere-turns may never exceed the M. M. F. impressed by the field between the pole faces.

The value of sparkless commutation is almost beyond price. Commutation has long been recognized as the greatest bugbear of continuous current machinery. Whatever adds to the life of the commutator adds to the durability of the machine, and the entire prevention of sparking is, therefore, an important feature. To be able also to have the brushes permanently fixed is of decided value, and this when taken with sparkless commutation makes a dynamo self-attendant to a greater degree than usual. The extra cost of applying these improvements to a dynamo is far more than balanced by the saving effected in materials, and the writers believe that the application of these methods of design in dynamos would make a pronounced and important step towards the practical perfection of this class of machinery.

NOTICE.

Written discussions of the paper contained in this issue if acceptable will be printed in the April number if received before April 1st.

The Secretary will esteem it a favor if his attention is called to any errors in either papers or discussion, in order that they may be corrected before printing the sheets for the annual volume.

The Institute as a body is not responsible either for the statements made, or for the opinions expressed, in the TRANSACTIONS.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, February 27th, 1895.

The 94th meeting of the INSTITUTE was held this date at 12 West 31st Street, and was called to order at 8 P. M. by President Houston.

THE PRESIDENT:—In the absence of Mr. Pope, our Secretary, who is unfortunately ill, Prof. Crocker has kindly offered to act as Secretary. The Secretary will please read the minutes of the last meeting.

Prof. Crocker read the minutes of the last meeting, and on motion they were adopted. He also read the following list of associate members elected and transferred at the council meeting in the afternoon.

Name.	Address.	Endorsed by
ANSON, FRANKLIN ROBERT	Manager, Salem Consolidated Street Railway Co., Salem, Ore.	F. L. Dame. P. S. Malcolm. W. C. Cheney.
CUMNER, ARTHUR B.	Senior Member, firm of Cumner, Craig & Co, 69 Broad Street, Boston, Mass.	S. S. Wheeler. F. B. Crocker. Geo. M. Phelps.
LECONTE, JOSEPH NISBET	Instructor in Electrical Engineering, State University, Berkeley, Cal.	C. L. Cory. F. F. Barbour. W. Meredith.
LOEWENHERZ, HERMANN	Mechanical Engineer, Met. Tel. and Tel. Co., 18 Cortlandt St., New York City; residence, 311 Hudson St., Hoboken, N. J.	Jos. Wetzler. Jno. J. Carty. T. C. Martin.
MACCULLOCH, ROBERT C.	Manager, Jos. Lough Electric Co., 503 Fifth Ave.; residence, 407 Lexington Ave., New York City.	H. W. Weller. J. G. Kirkegaard. R. W. Pope.
MAYER, MAXWELL M.	Manufacturer of Dynamos and Motors, 411 107th St., E. R.; residence, 242 E. 114th St., New York City.	A. L. Riker. O. P. Loomis. Jos. Wetzler.
NYHAN, J. T.	Superintendent and Electrician, Macon and Indian Spring Electric Railway, Macon, Ga.	W. F. D. Crane. Edw. Caldwell. R. W. Pope.
PADDOCK, B. C., JR.	Assistant in Generating Dept., Edison Elec. Illuminating Co. of Boston; residence, Brookline, Mass.	F. A. Pattison. Henry Floy. F. W. Erickson.

PRINCE, J. LLOYD	Engineer, 868 Flatbush Ave., Flatbush, N. Y.	F. B. Crocker. Max Osterberg. W. H. Freedman.
REDMAN, GEO. A.	General Supt., Electric Dept., Brush Elec. Light Co., and Rochester Gas and Elec Co., Rochester, N. Y.	F A. Scheffler. T C. Martin. H. A. Foster.
SWENSON, BERNARD VICTOR	Instructor in Electrical Engineering, University of Illinois, Champaign, Ill.	D. W. Shea. Sam'l Sheldon. Townsend Wolcott.

Total 11.

TRANSFERRED FROM ASSOCIATE TO FULL MEMBERSHIP.

Approved by Board of Examiners, December 17, 1894.

CROSBY, JAMES WELLINGTON	Electrical Engineer, Hix, Crosby & Co., New York City.
HIX, E. RANDOLPH	Firm of Hix, Crosby & Co., New York City.
BILLBERG, C. O. C.	Electrical Engineer, 3200 Arch St., Philadelphia, Pa.
CRAIG, JAMES HALLY	Firm of Cumner, Craig & Co., Boston, Mass.
SHAW, EDWIN C.	Manager, Akron General Electric Co., Akron, O.

Total 5.

Prof. Crocker also stated that the Council had decided to have the general meeting for this year held at Niagara Falls on Tuesday, June 18th, and has also changed a rule of the Council so that in the future ten gentlemen may be transferred from associate to full membership at any one meeting, instead of five. Heretofore the limit had been five, which necessitated keeping applicants on the list for a long time, and this change was thought necessary in view of the growth of the INSTITUTE.

THE PRESIDENT:—If there is no business which the INSTITUTE wishes to transact at this time, we will proceed to the paper of the evening, "Notes on Recent Electrical Engineering Development in France and England." It is not necessary to introduce to you Mr. H. Ward Leonard, who is so well known by all of us.

(Mr. Leonard read the paper. See page 129, February issue.)

Discussion.

Mr. Townsend Wolcott:—I would like to ask Mr. Leonard if he can account for the difference in the efficiency of the Parsons and the Laval turbines. There seems to be, according to the figures given in the paper, a great deal of difference in favor of the Parsons. I was not aware that there was any such difference. In fact, I thought that if there was any difference, the Laval was rather the better so far as coal consumption per horse power was concerned.

Mr. Leonard:—I do not think there is any difference, and if there is a difference I am inclined to think, also, that it is in favor of the Laval. The tests made by Professors Kennedy and Ewing were upon larger sized units than the ones in the case of the Laval. I fancy that it may be that the smaller size was influential.

Another point which may perhaps be a little confusing is this: that the consumption of steam quoted for the Laval steam turbine of 20 pounds of water per horse power hour is per horse power actually delivered, as you may say, in the generator armature. In other words, the friction of the bearing and the loss in the gearing is eliminated, and it is a horse power actually delivered, available in producing electric energy—of course, the efficiency of the armature is one thing left to consider—whereas the figures I quoted for indicated horse power are, of course, at the beginning before any of the friction is eliminated.

Mr. John W. Lieb, Jr.:—The author of this interesting paper informs us in the first few lines that his observations were made during a trip through England and France. Later on we find that in making a comparison with central station practice in this country, he has drawn his conclusions so as to cover in his comparison not only England and France, but the whole world, and in this generalization he has, I think, fallen into an error which should not pass unobserved. While there are no doubt many excellent central stations in England and France, it is generally admitted, I believe, that the best types of both the low-tension three-wire and the alternating current systems of distribution, are not to be found in the countries visited by Mr. Leonard. The claims of preëminence for American stations of these types, which the author has advanced, can be shown to be not well founded if the comparison is extended, as it should be, so as to include other European countries where central station construction has been less hampered by local legislation. I would therefore call attention to several stations in European countries not visited by the author, which, had he found it possible to visit them, would have won his admiration and made his comparisons more just to European central station practice.

I would in the first place cite as types of the three-wire low-tension central stations which the author did not visit, the central stations at Berlin. The Berlin stations have a combined

output inferior only to two or three stations in America. They supply with current a connected installation equivalent to about 95,000 amperes. The equipment of these stations—boilers, steam piping, engines, dynamos and electrical apparatus—would certainly not suffer by comparison with any of our best equipped and most recently constructed American stations. I am not in a position to quote any figures as to the economy of operation of the Berlin stations, having seen only one figure given as to the economy of generating. It is claimed that on the average throughout the year, 220 watts are delivered to the customers' premises per pound of coal, which is certainly an excellent economic performance. Although Mr. Leonard did not visit either the Dusseldorf or Hanover stations, both of these should have been included in such a comparison as he has made. In the case of the Hanover station, it is claimed that on an average during 1893, 220 watts were generated, and 180 watts delivered to the customer per pound of coal; Dusseldorf during the same period averaging 140 watts delivered per pound of coal. Neither of these stations would suffer by comparison with our best types of American low-tension stations. From the table compiled by the National Electric Light Association, including a number of American stations, it appears that the best 24 hours record covered by the table, gave 208 watts generated per pound of coal.

Coming to the alternate current stations which are included in the comparison, the author refers to conversion from 1,000 to 50 volts. As a matter of fact there are very few stations in England, France, or in Europe generally, transforming from 1,000 to 50 volts. The European standard for alternate current stations being 2,000 to 2,400 volts primary, transforming down to 100 to 110 volts secondary. Mr. Leonard has not included in his comparison with American statistics, the Vienna alternate current station, which would certainly not suffer by comparison with any station in the world. I must admit a limited familiarity with the alternate current stations in this country, owing to the fact that I have been abroad a number of years, but I think I am safe in saying that there is not an alternate current station in this country which in excellence of equipment, perfection of distribution, regularity of service, or economy in operation, is the equal of the Vienna station of the Internationale Electricitats Gessellschaft. Among the other European stations which ought certainly to be included in such comparisons as these, I would mention the alternate stations at Cologne and Rome. Both of these stations are excellent examples of alternating current station construction and contain characteristic types of modern equipment.

Passing along the paper I notice that the author calls attention to the system of charge to the consumer for current, used by Mr. Wright at Brighton. I would say at this time, that this system

of charging on the basis of what the author happily calls the "load factor of the consumer" was first developed by Prof. G. Colombo, of Milan, Italy, the general manager of the Italian Edison Company, and it is still the basis of charge for current delivered from the Milan Edison stations. This system was first adopted in 1887 or 1888, and has been in use ever since with entire satisfaction to the consumer. I do not know that a definite claim for precedence in the application of sliding scale of charge has been put forward, but I take this opportunity to mention it. According to the system of charging for current in use at Milan, the consumer is at liberty to choose between two systems of payment; either on the basis: first, of a fixed charge of a certain sum, 30 francs ($5.75) per lamp installed per year, plus a charge of 3½ centimes (.67c.) per lamp hour as registered by the meter, or, second, a charge per lamp hour as registered by the meter on a sliding scale at a rate varying from a maximum of 7.7 centimes (1.5c.) per lamp hour, to a minimum rate of 4.8 centimes (.96c.), depending upon the number of lamp hours used per month per lamp equivalent installed. This system covers fully and satisfactorily the question of a consumer's load factor, and gives the best consumer—that is, the one giving the company the greatest return per lamp installed,—the benefit of the best basic rate.

Another interesting point referred to by the author of the paper is the question of the station load factor. In Mr. Crompton's inaugural address before the *Institution of Electrical Engineers* in London, he presented a curve showing the load on all of the London stations combined, on the day of greatest output of last year, December 19th. The load factor on this day was shown to be 33 per cent. It may interest the members of the INSTITUTE to know that the load factor of the combined stations of the Edison Electric Illuminating Company of New York on the day of last year when the output was greatest (December 10th) was 34½ per cent. The load factor of the lower district supplied by the company, in which is included a large motor load, is somewhat less than 34 per cent.; the load factor of the upper district, which has only a small motor load, being slightly greater. The total K. W. hours of output of the combined London stations on the date referred to was 96,240. The combined output of the Edison stations in New York City on December 10th was 60,633 K. W. hours. The maximum load carried at any one time was in the case of the combined London stations, 11,600 K. W.; combined Edison stations in New York, 7,354 K. W. The connected installation in the case of the combined Edison stations in New York was: incandescent lamps, 234,494; arc lamps, 3,014; motors, 7,616 H. P.; or a total equivalent installed of 178,000 amperes. It may seem strange that the load factor of such a district as the lower district of New York City, in which the motor capacity connected (in K. W. equivalents) represents 42 per cent. of the total connected installation, is not greater than in the case of the

upper district, where the motor load represents only 16 per cent. of the installation. It should be remembered, however, that the lower district is eminently a business and industrial locality, and that after six o'clock the load curve drops off very rapidly to a minimum, while in the upper district we have a business and residential locality where the day load is light, but the evening load keeps up well and falls off gradually.

THE PRESIDENT:—In a paper so varied as this, and covering so many different fields, experts in which are present, unless a desire is expressed to the contrary I shall limit the speakers to ten minutes.

DR. CHAS. E. EMERY:—The author of the paper has in a racy and attractive way brought to the attention of those present, matters in which he has been interested and instructed abroad. For this pleasant duty, well performed, I am personally much obliged to Mr. Leonard.

Taking up my marginal notes in order; the paper on page 134 states that the Parsons steam turbine delivers one kilowatt for 28 pounds of feed water, and continues: "This is equivalent to "about 15.7 pounds of water per indicated horse-power per hour." The difference is so great it would seem that these figures need revision[1].

I have been interested in considering the possibilities of the Parsons and the Laval steam turbines. The high speed should permit the use of a small and comparatively cheap dynamo, and eventually the engines should not be as expensive as ordinary engines. Moreover, the very small space required is of importance in a large city. I have wondered why the turbines have not been introduced here. I made a special examination of the Laval steam turbine at the Columbian Exposition, and though I had a special invitation and wore a Judge's badge, I could not get the operator to put a load of more than three or four kilowatts on an engine rated at fifteen horse-power, the excuse being that there was water in the steam. The reported tests of this turbine are very satisfactory, but it is a question if it has yet been put in commercial form.

As to the question of the load factor, I think the critical point has not been referred to in the paper. It is a question more of the distribution of the load through the day than of the inequalities of local demands. It is considered unfortunate to take an elevator as an illustration, for, although it may take 15 to 20 kilowatts at times, and be shut off entirely for considerable intervals, the demand is distributed throughout the day and in apartment houses far into the night, and as it is very rare that the heavy

1. This may be explained by using rather low efficiencies. Twenty-eight pounds per kilowatt equals 20.89 pounds per E. H. P., of which 15.7 is practically .75, which is the joint efficiency of the engine and dynamo and corresponds approximately to 88 per cent. for the engine, and 90 per cent. for the dynamo, or *vice versa*.

pull required by each of a large number of elevators will come at the same moment, by the well understood law of averages, such elevators make a fairly uniform load. It is very much like the average in railroad work. When a few cars are running the fluctuations are very great, but as the number is increased, the load, though still fluctuating, gives a large load factor during the time of operation. It seems to me that the use of elevators and of electric current for various household uses should be encouraged, because such uses are distributed through a large number of hours per day. The real cause of the low load factor is, that so many consumers want light at the same time. The evident cure, if practicable, would be to charge a higher price during the rush hours. The method which would best appeal to consumers, would be to reduce the price for current used during other than the rush hours. The Wright plan mentioned in the paper (p. 140) with a proper scale of prices, would possibly accomplish these purposes, but the results would probably be better understood by consumers if expressed somewhat as above.

The description of the Heilmann electric locomotive and its operation is certainly very interesting, and involves some important considerations. It is fair to say that I had not thought of this system respectfully until I read the paper. It did seem to be impossible, when there are steam engines and a steam boiler already on a locomotive, to install an electric plant in addition to a steam plant on a special car, and in that roundabout way make a locomotive which would in any respect be more efficient than the direct use of steam applied to driving wheels in the first place. A few facts and some very simple calculations show that the idea is not as ridiculous as it seems. It would be unreasonable to dispute the statement that the cost of the power from an ordinary locomotive is double that of stationary engines of the best type. There are two reasons for this; one, the necessity of obtaining such an enormous power from a locomotive boiler which with the customary construction must be put in a certain place under limited conditions, the effect of all of which is to bring the evaporation down to 5 or at most 7 pounds instead of 8 or 9. The other is the difficulty of obtaining economy with the simple arrangement of valve gear which has been adopted and with such variable piston speeds as are necessary. If, therefore, the steam plant of the Heilmann locomotive can be operated, for one-half the fuel or anywhere near that, this saving, not considering interest charges, will more than compensate for the losses incident to the generation and utilization of electric current, even if the 50 per cent. extra weight of the Heilmann locomotive be considered as to that extent reducing the weight of the train. The question immediately arises, however; why not adopt the distinguishing features of the Heilmann steam plant to a steam locomotive? It is perfectly possible to mount a boiler of larger size on a platform and to make locomotive

steam cylinders which will operate as economically as those of an engine mounted on a platform itself, even if we have to increase the the size of the drivers to bring down the number of revolutions of the engine. Were this done, the locomotive would be as economical as the steam plant of the Heilmann locomotive and the intervening electric machinery would produce loss instead of gain. That is, when the progress that has been made in the construction of the Heilmann locomotive is analyzed along more general engineering lines, the improvement suggested is one in locomotives, and not specially in electric locomotives. Curiously enough the general features of the system have been already worked out for ordinary locomotives, but were so far ahead of the times that they have not been generally adopted. What was called the Farlie locomotive, built some years ago, had two boilers mounted on a platform supported on two trucks containing only driving wheels. The steam was introduced to the cylinders through ball and socket joints. The system operated well, all the weight was on the drivers, and I think some of the original engines are still at work in one of the South American states. The Mason Locomotive Works took up the system later, using a single boiler, and with one propelling truck containing drivers at one end, and an ordinary truck at the other. This arrangement enabled short curves to be run on suburban routes, but Mr. Forney, now present with us, showed that this could be done with a locomotive of the ordinary type, carrying its own tender on the frame, but supported by a truck, as evidenced in the locomotives on the elevated railroads, and the Mason system has not been extended. The success of the Heilmann system will then only show the desirability of reviving the Farlie system, perhaps using only a single boiler of large size.

At present, as Mr. Leonard suggests, it is well to encourage the development of the Heilmann system as a means of ascertaining the desirable details of a practical electrical locomotive, even if the steam machinery afterward be taken off, and the current supplied by some modification of the trolley system.

Mr. Herbert Lloyd:—The conclusions Mr. Leonard comes to, resulting from his inspection of a single battery plant in Paris, are, I think, a little unjust to accumulators. His figure of $107 per kilowatt for three hours' discharge, about conforms to the American practice, but the statement that a battery worked at this rate will not have an efficiency of over 60 per cent. is, I think, erroneous. All the large batteries installed in this country have been guaranteed at a much higher figure than 60; 75 is more common. In comparing the relative first cost of battery plant and direct power plant, Mr. Leonard gives a first cost for a direct plant of $50 per kilowatt of output as against $107 for a storage plant of the same output. I will quote the remarks of Mr. Edgar of Boston at the Cleveland Convention last week.

Mr. Edgar says:

"A first-class steam plant costs $100 a horse-power; everything "inside of the building. That is being done to-day. The battery "costs us a little over $50 a horse-power to do the maximum "work."

One hundred dollars a horse-power for direct plant means of course $133 per kilowatt, as against $107 for battery, taking Mr. Leonard's figures. I have had occasion within the past thirty days to get an estimate on a direct electric power plant, and the figure of $100 per horse-power is the result of my efforts.

Were the comparison made by Mr. Leonard between the first cost of the two systems correct, his later remarks as to the profitable application of a battery with a 40 per cent. load factor, would have some weight, but with batteries costing less per kilowatt of output than a direct plant, that contention falls.

Next, as to the idea of installing small batteries in customers' houses, that is going back to the earliest methods adopted in exploiting storage batteries in this country. In Haverford, Pennsylvania, this was tried eight or nine years ago, on a large scale, but the idea of dividing a battery up into a lot of little installations, distributed broadcast, is vastly less practical than the installing of one large plant in the central station, and if it would pay the customer to install a small battery, it would certainly pay the lighting company to install a large one, as the first cost would be proportionately less, and the care and cost of maintenance infinitely smaller.

Mr. Leonard's remark that: "The consumers' maximum load "will sometimes occur at the time of maximum load in the cen-"tral station, and when this accumulated load is put upon the "central station the kilowatts must be there to meet the de-"mand:" is one of the best arguments I have ever heard in favor of accumulators.

Mr. A. E. Kennelly: I think we are much indebted to Mr. Leonard for his interesting paper. A subject of this kind is always interesting, because, while, proverbially, comparisons are sometimes odious, practically, they are also sometimes very pleasant, and by seeing what our neighbors are doing we can often gain some advantage for ourselves.

There are three points in this paper I would like to mention. The first is that mentioned on page 130, namely that this country has suffered by having the electrical industry in the control of large corporations, and then on page 132 Mr. Leonard goes on to state that dynamos and engines are better here than they are anywhere. I suppose Mr. Leonard would not say that lamps are worse here than they are anywhere else, or that motors are worse here than they are anywhere else. So that we are forced to the conclusion that the superiority abroad must lie in the system of distribution, because there is nothing left but the systems to account for it. I can scarcely imagine that it can be maintained that in the commercial application of distribution there is a superiority

in European countries, because I think you have only to take up a map of England's electrical distribution systems for example, to see that the question of systems is a very rife one, and that there is no apparent uniformity of opinion as to which system is the best to employ, even under any given conditions. Thus it is stated by Mr. Leonard that under the most unfavorable conditions he can possibly imagine, an alternating system has been put in, in the middle of the city of London. He also mentions that dynamos cost much less here than abroad, and this in a country of corporate interference. Is that not an argument in favor of the fact that under the influence of aggregated capital, processes of manufacture may have been so perfected as to greatly reduce the cost of construction, and while no doubt the effect of large corporations is to limit and interfere in some directions with electrical applications, yet in this compensatory world the diminished price of electrical apparatus is an evidence of one beneficent effect of large corporations.

The second point is on page 139, where allusion is made to the cost of this storage battery as being capable of supplying 8,000 10 C. P. lamps for three hours, and costing about $30,000, meaning $107 per K. W. That is evidently based on an estimate of an inefficiency in the lamps of 3½ watts per candle. I would like to ask whether that 8,000 lamps is not the true estimate, and that 4½ and even 5 watts per candle would not be a much more fair basis to take, in which the cost would come to $75 or $83 per kilowatt.

The third point I want to draw attention to, is one that Dr. Emery has already mentioned, and I think that it deserves all the insistence that can be brought upon it, namely that on pages 141 and 142, of this load factor. When you sell light to customers they all practically enter into a conspiracy to throw the light on at the same time, just about dinner time, and you must have power in the station to supply it, but when you sell power to run intermittent 10 horse power motors, even though they each take 30 horse power at starting, by no possibility can the customers enter into any conspiracy to all start together, and all the figures based on such a conclusion with regard to electric elevator motors are greatly exaggerated in consequence, and the rates which should be charged for a kilowatt-hour based on elevator work are correspondingly exaggerated. As a matter of fact, I think it is well known that elevator load is objected to more on the score of the difficulty of maintaining regularity of pressure in the mains, than it is on account of the small load factor.

MR. WM. MAVER, JR.:—I should like to say that there is at least one electric light station in this country that transforms from 2,000 volts to 100 and to 50 volts; the converters being adjusted to either 100 or to 50 volts on the secondary. That is, I believe, the Manhattan Electric Light Company of this city. The change was made from 1,000 volts transforming to 50 in

the secondaries, over a year ago. Of course, however, they employ the two-wire system in the secondary. I should like to ask Mr. Leonard how the switching of the secondary circuit from the converter to the regular three-wire system in Brighton is performed. Others may be interested also in that. Also on page 134, whether the vulcanized rubber cables referred to are lead covered, or if not, in what way they are covered, if he knows; and also the manner in which the air is chemically dried before it is led into the ducts.

MR. M. N. FORNEY:—There are some things contained in this paper in relation to the Heilmann locomotive which interest me very much. I might say in the beginning that I know very little about electricity, but I know perhaps something about locomotives. There are several statements in this paper which are urged in favor of the locomotive, and which perhaps could hardly go entirely to the credit of the electric locomotive. For example, it is said that the Heilmann locomotive rests upon sixteen wheels, and on page 144 that Mr. Heilmann "is able to carry a larger "boiler, and hence does not have to crowd it to such a wasteful "point." Now it is not quite clear to me why you are not able on an ordinary locomotive to carry as large a boiler on sixteen wheels as on an electric locomotive. An ordinary locomotive and tender is always carried on sixteen wheels although the weights are not exactly the same, the Heilmann locomotive being heavier. The electric locomotive must in addition to the engine and boiler and the other appliances, carry its electric machinery besides. So that it appears as though the old steam locomotive has something to say for its side.

There is another statement on page 144 in which it is said that "probably at least one-third of the cost of maintenance of the "roadbed and the locomotives for high speed service could be "traced directly to this destructive hammer blow and side thrust." Now it would be interesting to know on what sort of evidence that statement is based. I confess that after being a student of railroad matters for a good while, I have never heard that so large a proportion of the repairs of roadbed can be assigned to any such cause as that. It is very true that experiments have been made showing that some very destructive action occurs in locomotives, in which there is an excessive amount of counterbalance. A good many cases have been quoted in which it is said that rails have been bent, and the experiments made at Purdue University also show that at very high speeds, with excessive counterbalance, the wheels raised up entirely clear of the rails. But it is also shown by the same experiments that there are substantially no injurious results when the locomotive is counterbalanced in a reasonable way.

On page 146, it is said that the cost of the Heilmann locomotive is $30,000. Now an ordinary passenger locomotive of the largest size can be obtained for about $10,000 to $12,000 at the

present time. There would therefore be a difference of about $18,000 to $20,000 in favor of the present steam locomotive. I think hardly any prudent business man would venture to make an investment of that kind without allowing ten per cent. on the extra cost to cover the interest and cost of replacing it. That would give you an excess of interest account for the Heilmann locomotive of $1,800 to $2,000. You may take it as a rough statement that a locomotive will burn per year about $2,500 worth of coal. I am taking a rough average through the country. As you have $1,800 to $2,000 excess of interest for the Heilmann locomotive, you would have to do the same amount of work with $500 to $700 worth of coal with the Heilmann locomotive that we are now doing with $2,500 worth on the steam locomotive.

I am entirely ignorant of the appliances used on the Heilmann locomotive, and there may be features there which would give a very great advantage in locomotive practice. But from the showing that is presented here, it seems to me that there is a good deal still to be said in favor of the steam locomotive.

DR. CARY T. HUTCHINSON:—It may be interesting to give some information about a large electric locomotive which has just been finished by the Baldwin Locomotive Works. This locomotive has eight drivers connected rigidly by side bars, making a wheel-base of 16 feet, the length over all being about 30 feet. The weight is 133,000 pounds uniformly distributed on the eight drivers, giving 16,700 pounds on each driver. There are four motors, one on each axle, the motors being built directly on the axle without springs of any kind between the armature and the axles.

The machine has a capacity, on a four hour test, of 1,000 horse power at a speed of 35 miles per hour. The regulation is the series parallel. The motor being: 1st, all in series; 2nd, two series by two in parallel; 3d, all four in parallel. There is also a resistance intended for use on first position in starting. The lowest speed, without resistance, is about seven miles per hour.

A test recently made at the Baldwin Locomotive Works showed an efficiency of more than 92 per cent. when operating 1,000 horse power.

The motors are designed so that they will work without sparking with full current in the armature at one-half normal field strength. That is to say, they will operate at any speed from 35 miles per hour up to about 65 miles per hour at the same power, the drawbar pull varying inversely as the speed. At speeds below 35 miles per hour the drawbar pull is constant, the power, therefore, being directly proportional to the speed.

The smoothness and absence of vibration was very noticeable in the test referred to. The entire machine was supported on four jacks, without bracings; when running with full torque, there was scarcely any shaking.

MR. W. L. BLISS:—On page 144 Mr. Leonard says: "But regardless of an abundant supply of steam from the boiler, we

"find ourselves greatly limited in power for steam locomotive "practice at high speed, because of the wire drawing of the "steam, and difficulty of properly exhausting when we run our "locomotive at its highest speed."

On page 145 he states further, "The engine in practice" (which I suppose is the engine which is driving the dynamo) "is "varied in speed from perhaps 50 to 500 revolutions, and the "strength of the generator field from zero to its maximum "strength." I have made a rough estimate here as to what that speed represented. In the first place, on page 144, Mr. Leonard complains that the high speed of the steam locomotive causes wire-drawing of, and difficulty in exhausting the steam, whereas these troubles are obviated in the Heilmann locomotive. He assumes, however, that in the Heilmann locomotive the prime mover runs up as high as 500 revolutions. I have made a little calculation on the margin. I remember that the Empire State locomotive No. 999 has 86 inch driving wheels. That would be a circumference of 22.2 feet. At 60 miles per hour the drivers would make 236 R. P. M., which is less than one-half as fast as the Heilmann locomotive would be going to make the same speed, on the assumption that the latter makes 60 miles per hour at 500 revolutions. If we go to 120 miles per hour (or 112 miles per hour, which is the record of the Empire State locomotive), we should not be running the same quite as fast as the Heilmann prime mover, so that I should think there would be no more difficulty with high piston speed and wire drawing in the Empire State than in the Heilmann locomotive, for the engines are evidently operating at nearly the same speed.

MR. RICHARD FLEMING:—In connection with the cost per kilowatt of the European dynamos, I would like to ask Mr. Leonard why the cost of the dynamos is higher there than here. Are they more liberally proportioned, or is the workmanship so much superior to ours that they have to charge more for them? Why is it? I would also like to state in connection with the use of the three-wire system on alternating lines, that in the winter of 1890-91 I built a small plant in the far west, in Washington, where I transformed from 1,000 volts in the primary to 208 volts in the secondary, using the Edison three-wire system. They were compelled to change from the regular continuous current three wire system to the alternating, and used the same wire. We used the standard Thomson-Houston transformer with primary windings in multiple, and secondary windings in series.

MR. JOSEPH SACHS:—The remarks made by the previous speaker, bring to my mind a similar instance of a small plant installed in 1889, in this city in the Lenox Lyceum, which was wired to be operated by the Edison three-wire system. Afterwards a small alternating plant was installed at the station of the New York Steam Heating Co. adjacent, and two Westinghouse

machines were put in, operated at 1,000 volts and the secondaries of the transformers operated at 50, were so employed as to operate all the three-wire Edison system in exactly the ordinary three-wire fashion. This was quite an original feature at the time, as not very much of this kind of work had been done at that date. I would also like to make a note of the line on page 135. "What is needed is a generator of electricity "directly driven by, or preferably constituting a part of the re- "volving disk, and here is food for considerable thought." I wish to say that several friends of mine at the present time are at work on such a device, and it has often seemed to me that it would be feasible to devise some form of unipolar or very simple commutating machine which could be coupled to the shaft of a very high speed turbine; and although the elements of friction, which is really the principal thing to be overcome in a case of that kind is very severe, I believe that such a device can be operated. A self-contained dynamo and engine of that kind would certainly be the acme of simplicity and cheapness. Professor Crocker may perhaps be able to give us some figures in regard to the coupling of unipolar dynamos at these speeds to turbines.

PROF. CROCKER:—I hardly think a subject of that magnitude can be considered a proper part of the discussion of a general paper of this kind. But I believe that some such device as you suggest can be made practicable. But it is such a large subject that it would require an evening for itself.

THE PRESIDENT:—Before calling on Mr. Leonard to close the discussion I wish to voice what I am sure are the sentiments of the meeting, by saying how much we have enjoyed this able paper, and how the value of the paper is evidenced by the very general discussion it has called forth.

I would like to say on my own part that I do not share Mr. Leonard's fear as to the evil effects of gigantic corporations, although I do not desire to be regarded as speaking unqualifiedly in favor of them. I do not think, however, that the statement made, that the practical development of engineering improvements is opposed by the gigantic corporations in the electric field, is warranted by the facts. On the contrary, if I have read aright the history of progress of electrical engineering science in this country, it has not been in spite of the gigantic corporations, but by reason of such corporations that such progress has been made. If here and there an inventor does not succeed in getting his particular system adopted by a corporation, he may, perhaps, naturally feel that such corporation stands in the way of its introduction. But we should not lose sight of the fact that these corporations are in the field for business and will be apt to buy anything that has real commercial value. It might be true, if all the corporations were represented by a single body, that such gigantic monopoly might absolutely discard anything of value.

But when we remember that there are several, perhaps, three or four or half-a-dozen, it is evident that a live company or corporation cannot fail to see the advantage of anything which possesses true merit.

I have shared the general surprise of probably some of you here in learning that the Heilmann locomotive, a locomotive that practically carries a central station with it, can show such favorable figures, as it appears to, regarding economy. It is a matter of great surprise to me, and I am rather disposed to think that a great deal of the supposed advantages possessed by the Heilmann locomotive, will in fact, be found to consist in an improvement on mechanical locomotive practice. If, however, it be true, what we have claimed for the great flexibility of electricity as a means of long distance transmission of power, will, it seems to me, to a very great extent be lost. It is a very interesting question, however, and I shall look to the solution of it with considerable interest. Of course, I recognize the question of speed as being in favor of the electric locomotive.

I will only say in conclusion, that as to Mr. Leonard's fear least all able consulting engineers should be controlled by these gigantic monopolies, that he affords a notable instance of an able one who I believe, has not yet been so controlled.

I will call now on Mr. Leonard to close this discussion.

MR. LEONARD:—I have so many points to answer that I hardly know where to begin. If I inadvertently embraced far more in the scope of my paper as regards the central stations abroad than I should have done, I regret it, and I can see upon reflection that there is cause for criticism if I have made remarks that are so sweeping as to involve stations which I did not see. In saying that undoubtedly we have the best three-wire central station plants in the world, I judged largely by my familiarity with those in this country by observation, and those abroad, which I have not seen, by published descriptions. But one point which I wish to mention is, that I do not consider that any conclusions can be arrived at in judging the matter by the question of how many watts are delivered to the customer per pound of coal. The coal in the cost of the central station energy is less than 10 per cent. of the cost. It may possibly be that such stations abroad may show better results than ours as judged by the statistics compiled by the National Electric Light Association. But I hardly think this would necessarily be a criterion either, because we all know the care with which statistics are prepared by foreigners and especially Germans, and we also most of us would be inclined to doubt whether all of the best of our United States stations had submitted full, detailed and accurate figures as to their production, to the committee that published the results in question. There are a great many points concerned in what I would consider the best three-wire plants, which are not at all covered nor rubbed out by the question of

the watts produced per pound of coal, and among them are the question of the perfection of distribution of pressure, the question of kilowatt hours produced per annum, per dollar of capitalization; and especially the question of how much earnings the station is making per dollar of investment, in which latter two points I am quite confident, although I have not the figures to back up the statement, that we are ahead of the European practice. I was very much surprised to hear one of the speakers state that the load factor of the New York Edison central station was 34 per cent., and I am almost forced to conclude that we differ as to the definition of load factor, for I had occasion personally to secure unquestionable returns in 1890 from the central stations in Chicago, Brooklyn, New York, Philadelphia and Boston, and at that time those stations averaged about 40 per cent. for the load factor and the New York station was the best of the lot, and I can only explain any such falling off as is represented by the present load factor of 34 per cent. as due to the taking on of too many of these fluctuating loads like elevators. As regards the question of the load factor again, I happened to be with the president of the Chicago Edison company on my visit abroad, and while there he received complete statistics from Chicago in regard to the operation in December, and the load factor there during December was over 50 per cent. The speaker perhaps did not understand that my remarks were limited as regards the quotation as to the load factor in London to the month of December in which, of course, the load factor is higher than would be ordinarily the case.

Another speaker spoke of 28 pounds per kilowatt hour not being correct relative to 15.7 pounds per indicated horse-power hour. I think these figures will bear scrutiny, and I call attention to the fact that the first one was in feed water per kilowatt hour in useful electric energy and not horse-power hour, and the second is per indicated horse-power hour.

As to the argument which has been presented by more than one, that while the Heilmann locomotive has a larger boiler that there is no reason why similarly a steam locomotive should not have a larger boiler, I beg to say that while I do not profess to have any very great amount of knowledge on that subject, I have given some considerable attention to it of late, and have noticed the comments and the writings of a good many persons who claim to be very well versed and apparently are, judging by their papers and by their standing, and the impression that I have derived is that there has been reached, very closely, a limit in the size of the steam locomotive boilers; that to make and place a larger boiler upon a locomotive to-day leads to such difficulties in many other ways as to be practically prohibitive, and I can only wonder if they can run with a steam boiler sufficiently large, why they burn twice as much coal as we do with stationary boilers. There seems to be no question that they do burn more

coal to produce a horse-power, and that it is due to the fact that they do have too small a boiler and crowd it too hard. If they can, why don't they put on a bigger boiler?

As to the cost of batteries, engines, etc., relative to each other, the figure of $107 per kilowatt I think is quite close to the mark of present practice, and I will say that in discussing this question with one of the best posted men in England, after considerable argument and figuring on his part, he stated that the cost of batteries, such as they made, would be $175 per kilowatt. As to the cost of engines, boilers and generators, I am satisfied that if any such figure as $100 per horse-power has been quoted, that it must have been intended not to cover the boiler, engine and dynamo merely, but possibly the value of the real estate and buildings, etc., which they represent also, and which I have not included in my figures, as there is no doubt but that large boilers, engines and dynamos can be procured not only at $50, but I believe at considerably less per kilowatt.

A criticism was made as to the suggestion of placing the batteries upon the consumer's premises instead of in the station. I think the speaker has lost sight of the fact that the only argument in favor of placing the battery in the position which I suggested, was to enable the customer to obviate the necessity of calling upon the central station for these large spurts of energy which he required with its consequent high cost due to small load factor at the rates I named. Placing the batteries in the central station would not correct the disturbance of lights or the drop in the conductors affecting other consumers, nor could the station afford to give to the customer such a low rate when these variations in the customer's load are still in existence, as he could if it was a constant current supplied to that customer for twenty-four hours per day. I must say that knowing the general views of American central station managers about storage batteries, I thought it would be rather in consonance with their ideas if they could get a customer to buy the batteries and maintain them.

As to the $300 per kilowatt, that $300 per kilowatt represents not of course, merely the boilers, engines and dynamos, but it represents the underground system which is very expensive per kilowatt, also the real estate and buildings, and possibly the usual percentage for the franchise, patents, etc.

I had no intention of impressing my hearers with the idea that the European practice was ahead of ours at the present moment. In fact, my opening clause stated that I was in doubt as regards the matter. But I did point out that they were making more progress than we were in this country in trying new methods, new apparatus and new combinations, diverging from the old beaten paths, and I consider that practice due to the fact that there are so many concerns over there which are considered first-class and are almost always in any competition which arises. In this country when a large central station plant is to be installed,

as we all know, it is not competed for by 25 or 30 concerns, the majority of whom are engineers who understand the entire construction of the work and manufacture the apparatus in addition; but generally the plants are built by the people themselves, by some one of their employes, merely purchasing the apparatus from some one or two or three manufacturing concerns.

As to the question of dynamos and motors and the argument that we have, as I thought, better dynamos and motors than they have abroad, I can only say that I think the best reason for this is that there are no patents on them which even the smallest concerns are afraid of, and therefore we do have active competition from the smaller concerns, which do not have large capitalization due to patents and heavy fixed charges, which necessitate the large profits of corporations such as I was commenting on.

The point as to the batteries not having been properly estimated by the fact that three and one-tenth watts was assumed, is not correct. The lamps were assumed at three and one-half watts per candle. Even if for the sake of argument it be assumed that the battery will cost $80 or $90 per kilowatt as against $50 for engine and boilers and dynamos, it would not affect the conclusion materially.

The argument was advanced that we ought not to consider the elevator as being a kind of load that was detrimental in its present state, because it is running all day long. But that does not alter the fact that if it does run all day long it only has a load factor of five per cent., and the revenue of that per kilowatt is only $131 per year, even at 30 cents per kilowatt hour, and that it will come on and be on the top of the peak of your maximum load. As an instance of that, I have a practical figure of an elevator which does require about 30 kilowatts to start it up, and its bill is $75 per month and it does come on the top of the peaks at the maximum load.

As to the plant in Brighton and the question of how they do the switching, I will say that in that instance the different sections I referred to are somewhat like the spokes of a wheel and there are only about four or five such switching points, and they do, in that instance, thus far control them by hand. That is, the operator goes and throws the switch and then goes to another point. But methods have been devised by which they can be handled from the central station automatically, and if there were any sufficient reason for it at Brighton it would have been done there, as they were fully aware of the method and its feasibility.

As to the underground system at Newcastle, the conductors are not lead covered, as I remember the matter, but are covered, I think, with jute or some similar material, and the air is chemically dried by being passed, I think, over chloride of lime.

As to why the cost of small dynamos and motors is higher in European practice than here I do not know; but I am inclined to think that one of the reasons is that in this country the

present popular method is for the manufacturers to bid on the machine delivered f. o. b. without any further work done in connection with it, and consequently there is very little chance for argument one over another, if the machines are very good and the competition is very keen. Whereas the method abroad is for the man who builds it to install it. In other words, the men who are manufacturers are generally electrical engineers, and they build and wish to install their own machines and consequently do not care to bid so low on the dynamo alone.

One of the speakers mentioned that there was no reason why there should be any more difficulty in the ordinary locomotive in taking care of the steam and using it economically in the cylinder and delivering it rapidly and exhausting it properly than there would be with the Heilmann locomotive. But I call attention to the fact while, of course, it is theoretically conceivable, that we should have a type of valves independently controlling the admission and exhaust in the ordinary locomotive, such as we have on stationary engines, we do not have them. It has been tried and retried and they have stuck to the simpler type of Stephenson link and slide valve, because the additional economies obtained by the use of the higher class of valve motion did not compensate for the additional complications introduced, which, however, does not apply at all to a steam engine placed above on a platform in which the most refined mechanism can be used to the best advantage.

I would like to call attention to one thing that I do not think I mentioned in the paper, and that is that by actual test by the engineer of the Chemin de Fer de L'Oest, who conducted the test of the Heilmann locomotive, they did operate the Heilmann locomotive over exactly the same distance, the same roadbed, running on the same time, hauling the same weight, the conditions being identical in every particular, and the amount of coal used by the Heilmann was 24 per cent. less than the amount used by their best compound locomotive.

A point which was made by one of the speakers was that there was no reason why if we used 16 wheels we should not be able to do just as well as the Heilmann does with its 16 wheels. It seems to me that it would be difficult to conceive a steam locomotive with 16 driving wheels. It would meet with difficulties upon the curves, and the rigidity of the steam locomotive is certainly going to be troublesome if we come to make a machine 50 feet long all upon the drivers, and I wish to emphasize the point that every pound of the weight of the Heilmann locomotive is resting on springs, and there is no such rigidity of the wheel base. There is the four-axle bogie at one end which has a flexible arrangement connecting it to the platform above, and a similar bogie at the other end, and there is no such difficulty as regards rigidity of construction as it seems to me would be met with in the steam locomotive under the same conditions.

And, furthermore, it impressed me that there is not an exact parallel, for the reason that a part of the 16 wheels counted as belonging to the steam locomotive by the speaker are on the tender and they are not at all effective for traction.

As regards the question of wear, and the statement that one-third of the cost of maintenance of roadbed and locomotive is represented by the destructive effects of the hammer blow and side thrust, I certainly would not dare to make any such figures as that for myself. I got that figure from a discussion which was held recently before the Civil Engineers' society and the figure was one which seemed to be agreed upon by more than one speaker. The speaker who named that figure, I think, was Mr. Strong. At any rate it was one whose name was familiar to me as that of a man who has had a very wide experience and is a pretty good judge of such matters and whose statement ought to be rather authoritative.

Another point I wish to bring out is this—they made measurements of deflection in crossing bridges in the case of the Heilmann locomotive and in the case of the compound reciprocating steam locomotive, and the deflection measurement showed that the deflection in the case of the steam locomotive was 80 per cent. more for the same weight than in the case of the Heilmann, which of course is attributable to this hammer blow effect, and which one of the speakers has pointed out has been found, in the case of a little error in the counterbalancing, to be sufficient to entirely lift the weight of the locomotive from the rails at times, as evidenced by tests at Purdue.

I agree with one of the speakers who said that he thought that our progress was not in spite of, but by reason of the big corporations; because I think that such progress in the engineering line, as we have been lately making, has necessarily been made by these corporations, because they have blocked other people who were trying to go ahead.

The same speaker mentioned the misfortune of losing the flexibility which we had all been attributing to the electric locomotive as compared to others, and that in the Heilmann that flexibility seemed to be lost. It seems to me it would be difficult to find a finer example of the flexibility of electrical transmission of power than is illustrated in the Heilmann locomotive. We can have an engine running at constant speed in one direction, and from that we can get any possible reduction or any torque we desire and any speed in either direction, and the flexibility is as perfect as is conceivable to my mind. In fact, it seems as though the electric energy were used there as a flexible connecting rod acting through an infinite number of gears, and acting between the source of power and the work that was to be done.

Another point which has occurred to me is that conceiving that we could put bigger boilers upon our locomotives, bigger

drivers and cylinders, until we finally could secure the horse-power necessary to handle the high speed or large loads, one difficulty which I have recently noted about an engine of that kind is that it cannot start. It may run at full speed when it is in motion all right, but even with the drivers we have to-day and with the boilers, etc., it is impossible for the Empire State express to start itself at Albany, and it is necessary that a freight locomotive, a slow speed locomotive with eight or ten drivers should come along at the other end of the train and push it before it can start. No such difficulty as that pertains to the Heilmann locomotive or any similar locomotive, because there is an unlimited torque for starting, and I point out that the two limitations in present practice for locomotives are it seems to me, that we want to go faster, that is one point and as to that, we have every advantage in connection with the electric locomotive; and the other point is, we want to pull more freight cars up a grade, and we can do that better with an electric locomotive than to my mind we can ever hope to do with a steam locomotive.

Communication Received After Adjournment.

Mr. Lloyd:—[*Communicated.*] Referring to Mr. Leonard's reply to the foregoing criticisms, (to which I had no opportunity of replying at the time,) I can only say that if Mr. Leonard denies that a first-class generating plant costs $100 per horse-power, he is mistaken. The remainder of his reply is simply facetious, and not logical or consistent. The experience of engineers in this country with batteries ten years ago has no bearing on the results obtained to-day. Apropos of this, if my information is correct, the express object of Mr. Leonard's visit to Europe was to investigate steam turbines, of which he speaks so glowingly, with the idea of adopting them for driving the generators used in the welding of street rails. Immediately on Mr. Leonard's return he contracted for the use of three complete battery installations to do this work instead of the steam turbines.

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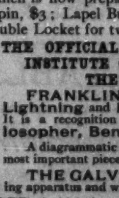

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